

CLAIMS

What is claimed:

1. A method of fabricating a semiconductor device, having a reduced-oxygen copper-zinc (Cu-Zn) alloy filled dual-inlaid interconnect structure formed on a copper (Cu) surface formed by electroplating the Cu surface in a chemical solution, comprising the steps of:
 - 5 providing a semiconductor substrate having a Cu surface formed in a via;
 - providing a chemical solution;
 - electroplating the Cu surface in the chemical solution, thereby forming a Cu-Zn alloy fill in the via and on the Cu surface;
 - 10 rinsing the Cu-Zn alloy fill in a solvent;
 - drying the Cu-Zn alloy fill under a gaseous flow;
 - annealing the Cu-Zn alloy fill formed in the via and on the Cu surface, thereby forming a reduced-oxygen Cu-Zn alloy fill;
 - planarizing the reduced-oxygen Cu-Zn alloy fill and the Cu surface, thereby completing formation of a reduced-oxygen Cu-Zn alloy filled dual-inlaid interconnect structure; and
 - 15 completing formation of the semiconductor device.
2. A method, as recited in Claim 1,
 - wherein the chemical solution is nontoxic and aqueous, and
 - wherein the chemical solution comprises:
 - 5 at least one zinc (Zn) ion source for providing a plurality of Zn ions;
 - at least one copper (Cu) ion source for providing a plurality of Cu ions;
 - at least one complexing agent for complexing the plurality of Cu ions;
 - at least one pH adjuster;
 - at least one wetting agent for stabilizing the chemical solution, all being dissolved in a volume of deionized (DI) water.

3. A method, as recited in Claim 2,
wherein the at least one zinc (Zn) ion source comprises at least one zinc salt selected
from a group consisting essentially of zinc acetate $((\text{CH}_3\text{CO}_2)_2\text{Zn})$, zinc
bromide (ZnBr_2) , zinc carbonate hydroxide $(\text{ZnCO}_3 \cdot 2\text{Zn}(\text{OH})_2)$, zinc
dichloride (ZnCl_2) , zinc citrate $((\text{O}_2\text{CCH}_2\text{C}(\text{OH})(\text{CO}_2)\text{CH}_2\text{CO}_2)_2\text{Zn}_3)$, zinc
iodide (ZnI_2) , zinc L-lactate $((\text{CH}_3\text{CH}(\text{OH})\text{CO}_2)_2\text{Zn})$, zinc nitrate $(\text{Zn}(\text{NO}_3)_2)$,
zinc stearate $((\text{CH}_3(\text{CH}_2)_{16}\text{CO}_2)_2\text{Zn})$, zinc sulfate (ZnSO_4) , zinc sulfide (ZnS) ,
zinc sulfite (ZnSO_3) , and their hydrates.

4. A method, as recited in Claim 2,
wherein the at least one copper (Cu) ion source comprises at least one copper salt
selected from a group consisting essentially of copper(I) acetate
 $(\text{CH}_3\text{CO}_2\text{Cu})$, copper(II) acetate $((\text{CH}_3\text{CO}_2)_2\text{Cu})$, copper(I) bromide (CuBr) ,
copper(II) bromide (CuBr_2) , copper(II) hydroxide $(\text{Cu}(\text{OH})_2)$, copper(II)
hydroxide phosphate $(\text{Cu}_2(\text{OH})\text{PO}_4)$, copper(I) iodide (CuI) , copper(II)
nitrate $((\text{CuNO}_3)_2)$, copper(II) sulfate (CuSO_4) , copper(I) sulfide (Cu_2S) ,
copper(II) sulfide (CuS) , copper(II) tartrate $((\text{CH}(\text{OH})\text{CO}_2)_2\text{Cu})$, and their
hydrates.

5. A method, as recited in Claim 1,
wherein said electroplating step comprises using an electroplating apparatus, and
wherein said electroplating apparatus comprises:
 - (a) a cathode-wafer;
 - (b) an anode;
 - (c) an electroplating vessel; and
 - (d) a voltage source.

6. A method, as recited in Claim 5,
wherein the cathode-wafer comprises the Cu surface, and
wherein the anode comprises at least one material selected from a group consisting
essentially of copper (Cu), a copper-platinum alloy (Cu-Pt), titanium (Ti),
platinum (Pt), a titanium-platinum alloy (Ti-Pt), an anodized copper-zinc
alloy (Cu-Zn, i.e., brass), a platinized titanium (Pt/Ti), and a platinized
copper-zinc (Pt/Cu-Zn, i.e., platinized brass).

7. A method, as recited in Claim 1,
wherein said semiconductor substrate further comprises a barrier layer formed in the
via under said Cu surface, and
wherein the barrier layer comprises at least one material selected from a group
consisting essentially of titanium silicon nitride ($\text{Ti}_x\text{Si}_y\text{N}_z$), tantalum nitride
(TaN), and tungsten nitride (W_xN_y).
8. A method, as recited in Claim 7,
wherein said semiconductor substrate further comprises an underlayer formed on the
barrier layer,
wherein said underlayer comprises at least one material selected from a group
consisting essentially of tin (Sn) and palladium (Pd), and
wherein said Cu surface is formed over said barrier layer and on said underlayer.
9. A method, as recited in Claim 8,
wherein said underlayer comprises a thickness range of approximately 15 Å to
approximately 50 Å,
wherein said barrier layer comprises a thickness range of approximately 30 Å to
approximately 50 Å,
wherein said Cu surface comprises a thickness range of approximately 50 Å to
approximately 70 Å, and
wherein said Cu-Zn alloy fill comprises a thickness range of approximately 300 Å to
approximately 700 Å.
10. A method, as recited in Claim 1,
wherein the annealing steps are performed in a temperature range of approximately
150°C to approximately 450°C, and
wherein the annealing steps are performed for a duration range of approximately 0.5
minutes to approximately 60 minutes.

11. A semiconductor device, having a reduced-oxygen copper-zinc (Cu-Zn) alloy filled dual-inlaid interconnect structure formed on a copper (Cu) surface formed by electroplating the Cu surface in a chemical solution, fabricated by a method comprising the steps of:

5 providing a semiconductor substrate having a Cu surface formed in a via;
 providing a chemical solution;
 electroplating the Cu surface in the chemical solution, thereby forming a Cu-Zn alloy
 fill in the via and on the Cu surface;
 rinsing the Cu-Zn alloy fill in a solvent;
 10 drying the Cu-Zn alloy fill under a gaseous flow;
 annealing the Cu-Zn alloy fill formed in the via and on the Cu surface, thereby forming
 a reduced-oxygen Cu-Zn alloy fill;
 planarizing the reduced-oxygen Cu-Zn alloy fill and the Cu surface, thereby completing
 formation of a reduced-oxygen Cu-Zn alloy filled dual-inlaid interconnect
 15 structure; and
 completing formation of the semiconductor device.

12. A device, as recited in Claim 11,
 wherein the chemical solution is nontoxic and aqueous, and
 wherein the chemical solution comprises:

5 at least one zinc (Zn) ion source for providing a plurality of Zn ions;
 at least one copper (Cu) ion source for providing a plurality of Cu ions;
 at least one complexing agent for complexing the plurality of Cu ions;
 at least one pH adjuster;
 at least one wetting agent for stabilizing the chemical solution, all being
 dissolved in a volume of deionized (DI) water.

13. A device, as recited in Claim 12,
 wherein the at least one zinc (Zn) ion source comprises at least one zinc salt selected
 from a group consisting essentially of zinc acetate $((\text{CH}_3\text{CO}_2)_2\text{Zn})$, zinc
 bromide (ZnBr_2) , zinc carbonate hydroxide $(\text{ZnCO}_3 \cdot 2\text{Zn}(\text{OH})_2)$, zinc
 5 dichloride (ZnCl_2) , zinc citrate $(\text{O}_2\text{CCH}_2\text{C}(\text{OH})(\text{CO}_2)\text{CH}_2\text{CO}_2)_2\text{Zn}_3$, zinc

iodide (ZnI_2), zinc L-lactate ($((\text{CH}_3\text{CH}(\text{OH})\text{CO}_2)_2\text{Zn})$, zinc nitrate ($\text{Zn}(\text{NO}_3)_2$), zinc stearate ($((\text{CH}_3(\text{CH}_2)_{16}\text{CO}_2)_2\text{Zn})$, zinc sulfate (ZnSO_4), zinc sulfide (ZnS), zinc sulfite (ZnSO_3), and their hydrates.

14. A device, as recited in Claim 12,

wherein the at least one copper (Cu) ion source comprises at least one copper salt

selected from a group consisting essentially of copper(I) acetate

($\text{CH}_3\text{CO}_2\text{Cu}$), copper(II) acetate ($((\text{CH}_3\text{CO}_2)_2\text{Cu})$, copper(I) bromide (CuBr),

copper(II) bromide (CuBr_2), copper(II) hydroxide ($\text{Cu}(\text{OH})_2$), copper(II)

hydroxide phosphate ($\text{Cu}_2(\text{OH})\text{PO}_4$), copper(I) iodide (CuI), copper(II)

nitrate hydrate ($((\text{CuNO}_3)_2)$), copper(II) sulfate (CuSO_4), copper(I) sulfide

(Cu_2S), copper(II) sulfide (CuS), copper(II) tartrate ($((\text{CH}(\text{OH})\text{CO}_2)_2\text{Cu})$, and

their hydrates.

15. A device, as recited in Claim 11,

wherein said electroplating step comprises using an electroplating apparatus, and

wherein said electroplating apparatus comprises:

(a) a cathode-wafer;

(b) an anode;

(c) an electroplating vessel; and

(d) a voltage source.

16. A device, as recited in Claim 15,

wherein the cathode-wafer comprises the Cu surface, and

wherein the anode comprises at least one material selected from a group consisting

essentially of copper (Cu), a copper-platinum alloy (Cu-Pt), titanium (Ti),

platinum (Pt), a titanium-platinum alloy (Ti-Pt), an anodized copper-zinc

alloy (Cu-Zn, i.e., brass), a platinized titanium (Pt/Ti), and a platinized

copper-zinc (Pt/Cu-Zn, i.e., platinized brass).

17. A device, as recited in Claim 11,
wherein said semiconductor substrate further comprises a barrier layer formed in the
via under said Cu surface, and
wherein the barrier layer comprises at least one material selected from a group
consisting essentially of titanium silicon nitride ($\text{Ti}_x\text{Si}_y\text{N}_z$), tantalum nitride
(TaN), and tungsten nitride (W_xN_y)
18. A device, as recited in Claim 17,
wherein said semiconductor substrate further comprises an underlayer formed on the
barrier layer,
wherein said underlayer comprises at least one material selected from a group
consisting essentially of tin (Sn) and palladium (Pd), and
wherein said Cu surface is formed over said barrier layer and on said underlayer.
19. A device, as recited in Claim 18,
wherein said underlayer comprises a thickness range of approximately 15 Å to
approximately 50 Å,
wherein said barrier layer comprises a thickness range of approximately 30 Å to
approximately 50 Å,
wherein said Cu surface comprises a thickness range of approximately 50 Å to
approximately 70 Å, and
wherein said Cu-Zn alloy fill comprises a thickness range of approximately 300 Å to
approximately 700 Å.
20. A semiconductor device, having a first interim reduced-oxygen copper-zinc (Cu-Zn)
alloy fill formed on a copper (Cu) surface and a second interim reduced-oxygen Cu-
Zn alloy fill formed on a Cu-fill, both films being formed by electroplating the Cu
surface and the Cu-fill, respectively, in a chemical solution, comprising:
a semiconductor substrate having a via; and
an encapsulated dual-inlaid interconnect structure formed and disposed in said via,
said interconnect structure comprising:
at least one Cu surface formed in said via;

a first interim reduced-oxygen Cu-Zn alloy fill formed and disposed on the at
least one Cu surface;
a Cu-fill formed and disposed on said interim reduced-oxygen Cu-Zn alloy
fill; and
a second interim reduced-oxygen Cu-Zn alloy fill formed and disposed on
the Cu-fill.